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IMIDAZOLINONE-TOLERANT RICE: WEED CONTROL, CROP RESPONSE, AND ENVIRONMENTAL
IMPACT

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Agronomy and Environmental Management

by

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ABSTRACT

Field and greenhouse research was conducted from 1999 to 2003 to evaluate weed control in imidazolinone-tolerant (IT) rice (*Oryza sativa* L.) under various tillage and planting systems, tolerance of IT rice cultivars to imazethapyr rate and application timing, and the impact of IT technology and tillage systems on solids runoff in rice drainage water. In both conventional and reduced tillage systems imazethapyr applied preemergence and postemergence at 70 g ai/ha controlled red rice (*Oryza sativa* L.), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], Amazon sprangletop [*Leptochloa panicoides* (Presl) Hitchc.], and rice flatsedge (*Cyperus iria* L.) 87 to 99%. Indian jointvetch (*Aeschynomene indica* L.) control with sequential applications of imazethapyr was as high as 70% in water-seeded rice but no more than 54% in drill-seeded rice. With sequential applications of imazethapyr at 70 g/ha, rice yield was 63% greater when water-seeded compared with drill-seeded. Imazethapyr applied to one- to two-leaf or three- to four-leaf rice at 70, 140, and 280 g/ha was more injurious to the IT rice cultivar 'CL 161' than to 'CL 121'. Shoot:root ratio for CL 161 was not affected by imazethapyr application. For CL 121, shoot:root ratio following imazethapyr application was lower than that observed for CL 161 suggesting that CL 121 shoot fresh weight was inhibited more by imazethapyr than was root fresh weight. Based on shoot fresh weight two weeks after imazethapyr application at 70 g/ha, CL 161 was 1.8 times more tolerant than CL 121 and CL 161 was 2.9 times more tolerant than CL 121 with 280 g/ha imazethapyr. In the conventional tillage and water-seeded system where soil was worked under flooded conditions one day prior to drainage, off-site movement of solids in the initial discharge of irrigation water was 1250 kg/ha. This compares with no more than 80 kg/ha for the initial drainage in reduced tillage systems where rice was water-seeded or drill-seeded. Total off-site movement of solids from initial drainage through 12 weeks totaled

2,370 kg/ha for the conventional tillage system and loss of solids was reduced by as much as 79% where reduced tillage systems were used.

CHAPTER 1

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crops in the world and is a major source of nutrition for people living in developing countries (Chang and Luh 1991). In 2003, rice production worldwide was approximately 390 million metric tons (mmt), of which 6.51 mmt were produced in the U.S. (Foreign Agriculture Service-USDA 2004). Major rice-producing states in the U.S. include Arkansas, California, Louisiana, Mississippi, Missouri, and Texas. In 2003, over 200,000 hectares (ha) of rice were planted in Louisiana (Anonymous 2004).

The majority of rice in Louisiana is grown in the northeast and southwest regions. The two regions differ in cultural management of rice due to differences in soil type, weather conditions, weed species, and tradition (Bollich 1992). Dry seeding is the predominant seeding method used in the northeast region, where red rice (*Oryza sativa* L.) is not a severe problem. Rice can be dry-seeded using a grain drill or by broadcasting seeds. Water-seeding is used primarily in the southwest region as a means to reduce red rice infestation. In a water-seeded system, presprouted rice seeds are broadcasted into a flooded field. Flooding during most of the growing season, creates an environment that is not conducive to germination of red rice seeds (Dunand 1988).

Conventional tillage is the predominant tillage system used in Louisiana. Numerous tillage operations are performed in the fall and spring to destroy weedy vegetation and to establish a firm and level seedbed. Proper seedbed preparation is considered essential for both drill- and water-seeded rice as it affects both rice seedling establishment and weed control through water management. In recent years, no-till and reduced tillage soil conservation practices have gained popularity in Louisiana rice production. In 2003, 26% of rice planted in Louisiana was grown under conservation

tillage (Anonymous 2004; Saichuk 2004). The advantages of conservation tillage include reduction or elimination of field operations that would be required for conventional seedbed preparation. Conservation tillage is also effective in reducing soil erosion and conserving soil moisture (Bollich 1992). Even so, poor seedling establishment and inconsistent red rice suppression may occur in conservation tillage systems (Bollich and Feagley 1995).

Red rice is commonly found in the southern U.S. and many other rice growing areas of the world (Pantone and Baker 1991). As early as 1846, red rice was considered a weed (Craigmiles 1978; Kwon et al. 1992). Dodson (1900) raised the possibility that red rice was brought into the U.S. from Honduras or Japan. In 2002, red rice was listed among the ten most troublesome weeds in rice-producing states including Louisiana, Mississippi, and Texas with Louisiana ranking it number one (Southern Weed Science Society 2002).

Until recently red rice was considered to be taxonomically identical to commercial rice (Hoagland and Paul 1978). The results of recent genetic studies have shown that this classification is inadequate and that there are at least three genetically distinct types of red rice (Vaughan et al. 2001). Some red rice species are appropriately classified as *Oryza sativa* ssp. *indica* while others are more closely related to *Oryza sativa* ssp. *japonica* cultivars. More importantly, some widely disbursed types of red rice are sufficiently distant from both to be considered a different species. These red rice accessions are very closely related to *Oryza nivara* and the noxious weed *Oryza rufipogon* (Vaughan et al. 2001).

The name red rice is derived from the red color of the seedcoat (pericarp) (Diarra et al. 1985). The red seedcoat of red rice interferes with the milling of commercial rice and delivery of rice with a significant percentage of red rice reduces price received (Smith 1979). Losses in rice grain yield due to red rice competition can be as high as 82% (Diarra et al.

1985). Four red rice plants per square meter cause an economic loss equivalent to about 20% of the potential value of the crop free of red rice (Navarro 1985). The estimated economic loss due to red rice infestation in the southern U.S. is approximately \$50 million a year (Smith 1979).

Red rice plants can be taller than common rice cultivars, which aids in red rice survival and dispersal (Noldin et al. 1999a). A single red rice plant has the capability of producing several hundred seeds. Unlike commercial rice, red rice seeds are prone to shattering (Cohn and Hughes 1981), i.e., as red rice seeds mature, they tend to fall off the plant reinfesting the field. Commercial rice seeds rarely survive through the winter, while red rice seeds are able to survive since they have the genetic trait of dormancy (Cohn and Hughes 1981). Red rice seeds develop a primary dormancy while attached to the rachis and shatter extensively after physiological maturity (Dodson 1898). Shattered red rice seeds are dormant and can remain viable in the soil for up to seven years (Diarra et al. 1985; Goss and Brown 1939). Consequently, total elimination of red rice from the soil seed bank would not be practical. Furthermore, conditions that promote and break dormancy in red rice are not well understood (Cohn and Hughes 1981).

Once a field is contaminated with red rice, rice production practices have to be altered to manage the weed. Rice grown in rotation with soybean has been used to reduce red rice populations (Griffin et al. 1991; Khodayari et al. 1987). Griffin and Harger (1986) recommended a two-year soybean and a one-year rice rotation to reduce red rice infestation levels. Problems with growing soybean in rotation with rice include reduced soybean yield potential due to poor soil drainage and the requirement of multiple herbicide applications for season-long control red rice control (Askew et al. 2000). In many cases red rice plants are not adequately controlled resulting in seed production, which contributes to problems in the subsequent crop.

In rice, water management following water seeding has been the most effective cultural method for red rice control (Dunand 1988). This practice maintains a saturated seedbed, which prevents red rice seeds from germinating by limiting the availability of oxygen (Dunand 1988; Griffin et al. 1986). In water-seeding, presprouted rice seeds are broadcasted aerially into a field with a six- to eight-cm flood. The flood is removed within three to five days after seeding to allow for rice seedling establishment. A flood is re-established within 7 days and the water level is maintained to allow rice leaves to stay above water. This program maintains a saturated soil environment which helps to prevent red rice germination. Herbicides have also been used in conjunction with water seeding to manage red rice. Molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate) applied preplant incorporated suppressed red rice emergence 92 to 100% four weeks after treatment; however, rice cultivars were injured 39 to 63% (Noldin et al. 1999b). Water seeding and herbicide use can reduce red rice infestation, but they do not provide complete control of red rice (Sanders and Jordan 1999).

The ability to control red rice in the rice crop has always been a goal in U.S. rice production (Craigmiles 1978). In 1993, an imidazolinone-tolerant (IT) rice line 93-AS-3510 was discovered through EMS seed mutagenesis (Croughan 1994). Since then, several rice cultivars tolerant to imidazolinones have been developed through breeding programs using 93-AS-3510 as the male parent line. 'CL 121' and 'CL 141', two IT rice cultivars developed from 93-AS-3510, are currently in commercial production. Another commercially used IT rice cultivar, 'CL 161', was directly developed from a mutated 'Cypress' plant (Wenefrida et al. 2004).

Imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid), an acetolactate synthase (ALS) (E.C.4.1.3.18) inhibitor, is the imidazolinone herbicide labeled for weed control in IT rice (Anonymous 2000). By inhibiting ALS, imazethapyr blocks

biosynthesis of branched-chain amino acids valine, leucine, and isoleucine, resulting in plant death of susceptible species (Stidham 1991). Imazethapyr controls many key weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash], and rice flatsedge (*Cyperus iria* L.) (Anonymous 2000; Bollich et al. 2002). Imazethapyr applied to IT rice also allows for selective control of red rice. Imazethapyr at 140 g ai/ha applied preemergence controlled red rice 90% (Kendig et al. 2000; Ohmes et al. 2001). Consistent control of red rice was observed with imazethapyr applied preemergence followed by application postemergence (Hackworth et al. 1998; Kurtz and Street 1999; White and Hackworth 1999).

Barnyardgrass, a highly competitive weed in rice, is common worldwide (Smith 1988). Propanil [N-(3,4-dichlorophenyl)propanamide] is a herbicide widely used for weed control in rice production (Smith 1965; Smith et al. 1977). Long-term and repeated use of propanil has resulted in development of propanil-resistant barnyardgrass (Baltazar and Smith 1994). Propanil-resistant barnyardgrass has been reported in Arkansas, Louisiana, and Texas (Carey et al. 1995). Thus, new herbicides with the potential to control propanil-resistant barnyardgrass have been a high priority. Masson and Webster (2001) reported that barnyardgrass was controlled at least 93% 28 days after postemergence treatment with imazethapyr. Barnyardgrass was controlled more than 85% 21 days after postemergence treatment with imazethapyr at 35 or 53 g/ha (Zhang et al. 2001). Season-long barnyardgrass control was greater than 80% with imazethapyr at 140 g/ha applied preplant incorporated and postemergence (Masson et al. 2001). Pellerin and Webster (2004) reported excellent control of barnyardgrass in drill- and water-seeded rice with imazethapyr applied preemergence followed by early postemergence or late postemergence.

Since IT rice is not resistant to imazethapyr the potential for rice injury is a concern. Steele et al. (1999) reported 16 to 48% rice injury with imazethapyr applied postemergence at 70, 105, 140, and 175 g/ha. Sanders et al. (1998) reported that sequential applications of imazethapyr at 70 g/ha resulted in 30% rice injury. However, Masson and Webster (2001) reported that rice injury was less than 16% when imazethapyr at 70 g/ha was applied to two- to three-leaf drill-seeded rice or water-seeded rice at pegging stage (green leaf tissue emerged from the seed and the root has extended downward into the soil).

Studies indicate that CL 121 and CL 161 differ greatly in their tolerance to imazethapyr. Wenefrida et al. (2004) reported that the difference in tolerance between CL 121 and CL 161 cultivars was due to the IT parent lines. PWC-16, the original IT germplasm for CL 161, based on seed germination experiments, is eight times more tolerant than 93-AS-3510, the male parent line for CL 121. The differential tolerance is most likely a physiological response to imazethapyr. Studies have indicated that ALS inhibitors can reduce transport of photosynthate from source leaves to roots, resulting in root growth inhibition (Devine 1989; Devine et al. 1990; Shaner 1991). In a greenhouse study, Zhang and Webster (2002) reported that tolerance of rice to bispyribac-sodium {2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate}, also an ALS inhibitor, was cultivar and growth stage dependent. They found that medium-grain cultivar 'Bengal' was less tolerant to bispyribac compared with long-grain cultivar 'Cocodrie'. It was observed that shoot and root growth of 'Bengal' was inhibited more when bispyribac was applied to one- to two-leaf rice compared with two- to three-leaf rice. Pantone and Baker (1992) reported that long-grain 'Lemont' rice was less tolerant to triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid than medium-grain 'Mars' rice or long-grain 'Tebonnet' rice. All cultivars were more tolerant to

triclopyr as rice growth stage advanced from two- to three-leaf to panicle initiation.

A broad spectrum of weed control with a wide window of application timing is characteristic of imidazolinone herbicides (Monks et al. 1996; Newhouse et al. 1992). Imidazolinone herbicides have very high potency, which means they can be applied at relatively low use rates (Newhouse et al. 1991) and also have low mammalian toxicity since the biosynthetic pathway catalyzed by the ALS enzyme does not exist in animals. Furthermore, in laboratory rats, these herbicides were rapidly excreted before accumulation occurred in blood or tissue (Harris et al. 1991).

The ability to selectively control red rice in IT rice with imidazolinone herbicide suggests that cultural practices such as water seeding, cultivation under flooded conditions, and pinpoint water management for suppression of red rice may not be necessary. Tillage after flooding operations result in the release of significant amounts of solids and nutrients once the field is drained after planting, and rice field discharges have been associated with water quality degradation in receiving streams in the Mermentau River Basin (Cormier et al. 1990). By using herbicide tolerant rice varieties, however, the practice of tillage after flood to control red rice, and the environmental concerns associated with this practice would be eliminated. Water planting using clear water or no-till methods could continue to be utilized. No-till water seeding can significantly reduce the level of total solids contained in rice field drainage water released after planting (Bollich and Feagley 1995). In water-seeded rice, discharges from fields have been linked to water quality degradation in surface waters (Bollich and Feagley 1995; Cormier et al. 1990; Salassi et al. 2002).

A dry-seeded system has many environmental and economic advantages when compared to water planting of rice. When wet springs occur, the amount of tillage required for conventional seedbed preparation generally increases,

and planting is delayed. The additional tillage operations result in higher production costs and delays in planting can result in decreased yields (Bollich et al. 1992). Water planting of rice, however, must be an option available for rice growers. In a wet spring, when the fields are too wet to drill-seed, water seeding of rice is the only option available.

Alternative management practices such as no-till, stale seedbed, and reduced tillage have reduced the amount of sediment in water runoff from rice fields (Bollich and Feagley 1995; Feagley et al. 1992); however, poor seedling establishment and inconsistent red rice control were associated with those practices (Bollich and Feagley 1995; Linscombe et al. 1999). Use of IT rice may not only allow for effective control of red rice and other weeds, but may also encourage a shift toward more environmentally friendly practices such as reduced tillage and drill seeding. Information, however, is limited as to how tillage systems, seeding methods, water management, rice cultivar selection, and herbicide programs may affect solids runoff.

Therefore, the research for this dissertation addressed the following objectives:

1. To study the effect of cultural practices on weed control, crop response, and yield components in IT rice.
2. To evaluate shoot and root growth of IT rice cultivars in response to imazethapyr application rates and timings.
3. To study the effect of existing and alternative rice production systems on off-site movement of solids from fields.

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CHAPTER 2

EFFECT OF CULTURAL PRACTICES ON WEED CONTROL AND CROP RESPONSE IN IMIDAZOLINONE-TOLERANT RICE

Introduction

Rice (*Oryza sativa* L.) is an important crop in Louisiana with over 200,000 hectares (ha) grown in 2003 (Anonymous 2004). The majority of rice in Louisiana is grown in the northeast and southwest regions which have unique cultural management systems due to differences in soil type, weather, weed species, and tradition (Bollich 1992). Dry seeding is the predominant seeding method used in the northeast Louisiana rice growing areas where red rice (*Oryza sativa* L.) is not a severe problem. Rice can be dry-seeded using either a grain drill or by broadcasting seeds. Water seeding is used primarily in the southwest rice growing areas as a means to reduce red rice competition. In water seeding, pregerminated rice seeds are aurally broadcasted into flooded fields. Using pinpoint flood water management, water is removed within three to five days after planting to allow for rice seedling establishment and the permanent flood is established within seven days. This planting system creates a soil environment that reduces germination of red rice seed in the soil (Dunand 1988).

Conventional tillage usually consisting of numerous field operations in the fall and spring to destroy weedy vegetation and establish a firm and level seedbed is the predominant tillage system used in Louisiana (Bollich 1992). Proper seedbed preparation is considered essential for both drill- and water-seeded rice since it affects rice seedling establishment as well as weed control through water management. In recent years, conservation tillage to include no-tillage and reduced tillage programs has gained popularity in Louisiana rice production. In 2003, some form of conservation tillage was used on 26% of rice planted in Louisiana (Anonymous 2004; Saichuk 2004). The advantages of conservation tillage include reduction or elimination of field

operations, reduction in soil erosion, and conservation of soil moisture (Bollich 1992). However, poor rice seedling establishment and inconsistent red rice control may occur in conservation tillage systems (Bollich and Feagley 1995).

Red rice is a weedy rice biotype that is considered the most troublesome weed in Louisiana rice production (Sanders and Jordan 1999). It reduces rice grain yield through competition and causes reduction in milling yields and grade. Rice yield reductions as high as 82% from season-long red rice interference were reported in Arkansas (Diarra et al. 1985). Four red rice plants per square meter caused an approximate economic loss of 20% (Navarro 1985). Red rice in the rice-producing states of the southern U.S. causes an estimated \$50 million loss each year (Smith 1979).

Until recently the genetic similarity of domestic rice and red rice prevented selective control with herbicides. The most effective control program for red rice was water seeding in combination with a pinpoint flood and herbicides (Dunand 1988; Griffin et al. 1986). Use of molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate) preplant incorporated in a water-seeded system controlled red rice 92 to 100% four weeks after treatment but, rice cultivars were injured 39 to 63% (Noldin et al. 1999). Even the best combination of cultural and chemical control methods will not provide season-long control of red rice (Sanders and Jordan 1999).

In 1993, an imidazolinone-tolerant (IT) rice line 93-AS-3510 was discovered when mutated seed survived an imidazolinone herbicide application (Croughan 1994). Since then, several rice cultivars tolerant to imidazolinone herbicide have been developed through breeding programs by using 93-AS-3510 as the male parent line. 'CL 121', one IT rice cultivar, is currently in commercial production. Imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid), an acetolactate synthase (ALS) (E.C.4.1.3.18) inhibitor, is the imidazolinone

herbicide labeled for use in IT rice (Anonymous 2000). By inhibiting the ALS enzyme, imazethapyr blocks biosynthesis of branched-chain amino acids valine, leucine, and isoleucine, resulting in plant death of susceptible species (Stidham 1991). Imazethapyr controls many key weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash], and rice flatsedge (*Cyperus iria* L.) (Anonymous 2000; Bollich et al. 2002). More importantly imazethapyr in combination with IT rice allows for selective control of red rice. In drill-seeded rice, a soil application of imazethapyr at 140 g ai/ha controlled red rice 90% (Kendig et al. 2000; Ohmes et al. 2001). In other studies, consistent control of red rice was observed with imazethapyr applied preemergence (PRE) followed by postemergence (POST) in drill-seeded rice (Hackworth et al. 1998; Kurtz and Street 1999; White and Hackworth 1999). Pellerin et al. (2004), however, reported that red rice control in drill-seeded rice 35 days after treatment was no more than 81% with imazethapyr applied sequentially PRE and POST. Imazethapyr applied at 87 g/ha applied to the soil surface before flooding in water-seeded rice and followed by 53 g/ha postemergence controlled red rice 90 to 96% 21 days after POST application (Pellerin et al. 2003).

Most research with IT rice has been conducted using a drill-seeded system and information is limited for water-seeded rice. In addition, little research has been conducted in conservation tillage systems using IT rice. Therefore, the objective of this study was to evaluate crop response and weed control under conventional and reduced tillage in both drill-seeded and water-seeded culture using IT rice.

Materials and Methods

Five experiments were conducted at the Rice Research Station near Crowley, LA, in 1999, 2000, and 2001 on a Crowley silt loam soil (fine montmorillinitic, thermic Typic Albaqualf), with pH 6.4 and 1.4% organic

matter. Seedbed preparation for conventional tillage included a fall disking followed by spring disking and two passes in the opposite direction using a two-way bed conditioner equipped with rolling baskets and s-tine harrow set to operate at 6-cm deep. Reduced tillage plots received no mechanical seedbed preparation in the spring. Two weeks prior to seeding, the reduced tillage area was sprayed with glyphosate at 0.84 kg ae/ha to control existing vegetation. Water-seeded plots were 1.5-m wide by 5-m long and drill-seeded plots consisted of eight 19 cm spaced rows 5-m long.

IT rice 93-AS-3510 was planted in 1999 and CL 121 was planted in 2000 and 2001. The drill-seeded areas were planted on May 6, May 27, and May 31, in 1999, 2000, and 2001, respectively, at a seeding rate of 112 kg/ha and at a depth of 1.5 cm. All plots were surface irrigated after drill seeding. Water-seeded areas were planted one day after each drill seeding date by hand broadcasting presprouted rice seed into flooded plots at a seeding rate of 168 kg/ha. After seeding, the field was drained for seedling establishment. Both the drill- and water-seeded areas were surface irrigated at the two- to three-leaf stage and a 5-cm permanent flood was established at the four- to five-leaf stage. Soil fertility management consisted of 280 kg/ha of 7-21-21 (N-P₂O₅-K₂O) fertilizer preplant and 280 kg/ha of 46-0-0 (N-P₂O₅-K₂O) urea nitrogen applied immediately before the permanent flood establishment. Standard agronomic and pest management practices were implemented throughout the growing season to maximize yields.

The experimental design was a split-split plot in a randomized complete block with four replications. The whole plots consisted of conventional tillage and reduced tillage systems. The subplots consisted of drill and water seeding. The sub-sub plots consisted of imazethapyr at 70 g/ha applied PRE followed by imazethapyr at 70 g/ha applied POST to three- to four-leaf rice, imazethapyr at 105 g/ha PRE followed by 70 g/ha POST to three- to four-leaf rice, and no imazethapyr. All herbicides were applied with a CO₂-

backpack sprayer calibrated to deliver 140 L/ha at 186 kPa. A nonionic surfactant¹ at 0.25% (v/v) was added to all imazethapyr POST treatments.

Visual estimates of weed control and rice injury were determined on a scale of 0 to 100% with 0 = no control or injury and 100 = plant death. Injury was based on chlorosis, necrosis, and height reduction. Barnyardgrass, Amazon sprangletop [*Leptochloa panicoides* (Presl) Hitchc.], rice flatsedge, and red rice were evaluated 14 and 35 days after POST treatment. Indian jointvetch (*Aeschynomene indica* L.) control was evaluated 35 days after POST treatment. Days to 50% heading was determined by calculating the time period from planting until 50% of rice had visible panicles. Plant height was recorded at harvest by measuring from the ground to the tip of the extended panicle with a sample size of three per plot. Lodging of rice plants was estimated on a scale of one (erect) to nine (prostrate). At maturity, a randomly selected area of one square meter from each plot was harvested to determine dry seed weight, number of culms, and culm dry weight. Ten rice panicles were randomly selected to determine seed per panicle and seed weight per panicle. Percent seed was used as a harvest index and was calculated by dividing total dry seed weight by total above ground plant dry matter multiplied by 100. This parameter characterizes the proportion of the total plant dry weight attributed to seed production. Rice was harvested with a small-plot combine. Percent grain moisture was measured and rough rice yield was adjusted to 12% moisture content. All data were subjected to the Mixed Procedure (SAS Institute 1999), with locations and years being used as random-effect parameters. Considering year or combination of year and location as environmental or random effects permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III Statistics were used to test all the fixed effects or

¹ Nonionic surfactant Latron AG-98® is a mixture of alkylaryl polyoxyethylene glycols. Rohm and Haas. 100 Independence Mall West, Philadelphia, PA 19106.

interactions between the fixed effects and least square means at $p \geq 0.05$ were used for mean separation.

Results and Discussion

Tillage system by seeding method by imazethapyr treatment interactions were not observed for any of the parameters evaluated. An imazethapyr treatment effect, however, was observed for Amazon sprangletop control, days to 50% heading, seeds per panicle, seed weight per panicle, and percent seed harvest index. Data were averaged over conventional and reduced tillage systems and drill- and water-seeding methods. Tillage system by imazethapyr treatment interactions were observed for culm number and culm weight, and data were averaged over seeding methods. Seeding method by imazethapyr interaction was observed for Indian jointvetch control, panicle height, lodging, and rice grain yield, and data were averaged over tillage systems.

Control of barnyardgrass, rice flatsedge, and red rice averaged 97 to 99% with imazethapyr at both 14 and 35 days after POST treatment with no differences observed between the imazethapyr PRE/POST programs (Table 2.1). In contrast, Amazon sprangletop control at both rating dates was greater for imazethapyr PRE at 105 g/ha followed by imazethapyr POST compared with imazethapyr at 70 g/ha PRE followed by POST application. This level of control was for Amazon sprangletop similar to that observed by Webster (2004). In the present study when imazethapyr was applied sequentially, Indian jointvetch control was equivalent within each seeding method (Table 2.2). Indian jointvetch control, however, averaged 12 and 16 percentage points greater in water-seeded rice compared with drill-seeded rice, but control did not exceed 70%. Masson and Webster (2001) reported that Indian jointvetch control ranged from 44 to 74% 28 days following imazethapyr application in water-seeded IT rice.

Differences among imazethapyr treatments were not observed for days to 50% heading, seeds per panicle, seed weight per panicle, or percent seed

Table 2.1. Control of barnyardgrass, Amazon sprangletop, rice flatsedge, and red rice with imazethapyr at 14 and 35 days after postemergence treatment at Crowley, Louisiana in 1999, 2000, and 2001.^a

Imazethapyr ^b		Barnyardgrass	Amazon sprangletop	Rice flatsedge	Red rice
PRE	POST				
— g ai/ha —		—— Weed control ^c , %, 14 days after treatment ——			
70	70	98 a	89 b	97 a	98 a
105	70	98 a	91 a	97 a	98 a
		—— Weed control ^c , %, 35 days after treatment ——			
70	70	99 a	87 b	98 a	99 a
105	70	99 a	91 a	98 a	99 a

^aData averaged over conventional and reduced tillage systems, drill- and water-seeding methods, and five experiments.

^bPRE, preemergence application; POST, postemergence application to three- to four-leaf rice.

^cMeans followed by same letter in a column within each rating interval are not significantly different at $p \leq 0.05$.

Table 2.2. Control of Indian jointvetch with imazethapyr at 35 days after postemergence treatment under drill- and water-seeded environments at Crowley, Louisiana in 1999, 2000, and 2001.^a

Imazethapyr ^b		Control ^c	
PRE	POST	Drill-seeded	Water-seeded
— g ai/ha —		————— % —————	
70	70	53 b	65 a
105	70	54 b	70 a

^aData averaged over conventional and reduced tillage systems and five experiments.

^bPRE, preemergence application; POST, postemergence application to three- to four-leaf rice.

^cMeans followed by same letter are not significantly different at $p \leq 0.05$.

harvest index (Table 2.3). However, a reduction of 27% in days to 50% heading was delayed 18 days and a reduction of 80% in seeds per panicle, 84% in seed weight per panicle, and 100% in percent seed harvest index occurred when imazethapyr was not applied. These reductions were attributed to weed competition.

For both culm number and culm weight, differences between imazethapyr treatments were not observed within each tillage system (Table 2.4). Regardless of imazethapyr treatment, culm number was reduced 28% and culm weight 32% for the reduced tillage system compared with the conventional tillage system, indicating that seedling establishment was a problem in the reduced tillage system. Bollich and Feagley (1995) also observed poor seedling establishment in reduced tillage compared with conventional tillage. When imazethapyr was not applied, differences in culm number or culm weight between tillage systems were not noted. Significant reduction (90%) for both parameters occurred, however, when imazethapyr was not applied, again indicating the effect of weed competition.

There were no differences in panicle height or in lodging when imazethapyr was applied regardless of imazethapyr treatment, tillage, or seeding method (Table 2.5). Panicle height averaged 92 cm and lodging was 2. When imazethapyr was not applied, panicle height was 33 cm for water-seeded rice and almost twice that of drill-seeded rice; lodging was reduced from 8 in drill-seeded to 6 in water-seeded rice.

Rice grain yield was 63% greater when imazethapyr was applied at 70 g/ha PRE and 23% greater when applied at 105 g/ha PRE in water-seeded compared with drill-seeded rice (Table 2.5). However, no difference was observed among imazethapyr treatments within each seeding method. Improved control of weeds such as Indian jointvetch (Table 2.2) in water-seeded rice probably contributed to rice grain yield increases. In drill-seeded rice where imazethapyr was applied, yield averaged 6.5 times that of the

Table 2.3. Days to 50 percent heading, number of seed per panicle, seed weight per panicle, and percent seed harvest index following imazethapyr treatments at Crowley, Louisiana in 1999, 2000, and 2001.^a

Imazethapyr ^b		Parameters ^c			
PRE	POST	Days to 50% heading	Seeds per panicle	Seed weight per panicle	Percent seed ^d
— g ai/ha —		— d —	Number	— g —	— % —
70	70	68 a	80 a	1.68 a	26.4 a
105	70	68 a	80 a	1.71 a	26.8 a
Nontreated		50 b	16 b	0.28 b	0.1 b

^aData averaged over conventional and reduced tillage systems, drill- and water-seeding methods, and five experiments.

^bPRE, preemergence application; POST, postemergence application to three- to four-leaf rice.

^cMeans followed by same letter within a column are not significantly different at $p \leq 0.05$.

^dPercent seed is a harvest index calculated by dividing total dry seed weight by total above ground plant dry matter multiplied by 100.

Table 2.4. Culm number and culm weight following imazethapyr treatment used in conventional and reduced tillage systems at Crowley, Louisiana in 1999, 2000, and 2001.^a

Imazethapyr ^b		Tillage system ^c	
PRE	POST	Conventional	Reduced
— g ai/ha —		Culm number/m ²	
70	70	680 a	500 b
105	70	750 a	540 b
Nontreated		70 c	50 c
		Culm weight kg/m ²	
70	70	1.2 a	0.8 b
105	70	1.3 a	0.9 b
Nontreated		0.1 c	0.1 c

^aData averaged over drill- and water-seeding methods and five experiments.

^bPRE, preemergence application; POST, postemergence application to three- to four-leaf rice.

^cMeans followed by same letter for each parameter are not significantly different at $p \leq 0.05$.

Table 2.5. Panicle height, lodging, and yield with imazethapyr treatment used in drill- and water-seeded environments at Crowley, Louisiana in 1999, 2000, and 2001.^a

Imazethapyr ^b		Seeding method ^c	
PRE	POST	Drill-seeded	Water-seeded
— g ai/ha —		Panicle height, cm	
70	70	92 a	92 a
105	70	92 a	91 a
Nontreated		16 c	33 b
		Lodging 0-9	
70	70	2 a	2 a
105	70	2 a	2 a
Nontreated		8 c	6 b
		Yield, kg/ha	
70	70	3490 b	5670 a
105	70	4660 b	5710 a
Nontreated		630 d	1710 c

^aData averaged over conventional and reduced tillage systems and five experiments.

^bPRE, preemergence application; POST, postemergence application to three- to four-leaf rice.

^cMeans followed by same letter for each parameter are not significantly different at $p \leq 0.05$.

nontreated control. In water-seeded rice where imazethapyr was applied yield was 3.3 times that of the untreated control. Even though yields where imazethapyr was not applied in the water-seeded system were only 1710 kg/ha, yield was 2.7 times that for the drill-seeded system. Higher yield in the water-seeded system was the result of increased weed interference in the drill-seeded system. Weed competition also resulted in increased lodging which further decreased yield in the drill-seeded system. This further substantiates the conclusion that a water-seeded system was more conducive to rice production.

In summary, imazethapyr applied PRE and followed by a POST application controlled barnyardgrass, rice flatsedge, and red rice at least 98% and Amazon sprangletop 87 to 91% 35 day after POST application regardless of tillage system or seeding method. The control of red rice in this study in both drill- and water-seeded rice was in contrast to findings of Pellerin et al. (2003 and 2004) where red rice control with imazethapyr was greater in water-seeded than drill-seeded rice. The lower red rice control in drill-seeded rice (Pellerin et al. 2004) was probably due to imazethapyr rate and timing of application. Pellerin applied 87 g/ha at planting followed by 53 g/ha POST. This lower rate applied POST may not be sufficient to control red rice at a tillering stage. Many factors such as planting date, seeding depth, and cultivar selection can alter the time between planting application and POST application. Developmental stage of red rice has been shown to affect control using POST applications (Masson et al., 2001). Control of Indian jointvetch with imazethapyr was greater in the water-seeding system but was no greater than 70% 35 days after postemergence treatment. When imazethapyr was applied, days to 50% heading, seed per panicle, seed weight, and percent seed harvest index were not affected by tillage system or seeding method. Culm number and culm weight were greater in the conventional tillage system compared with reduced tillage when imazethapyr was applied, but were not

affected by seeding method. Rice grain yield when imazethapyr was applied PRE followed by POST was greater in water-seeded compared with drill-seeded rice.

Previous research had provided information on weed control in water-seeded or drill-seeded systems. This research compares weed control in water-seeded and drill-seeded systems. The results clearly show that imazethapyr applied sequentially to IT rice can provide control of many key weeds including red rice in both water-seeded and drill-seeded systems, even when tillage operations are eliminated. No differences in tillage systems for weed control, days to 50% heading, seed number or weight per panicle, percent seed, panicle height, lodging, or yield were observed. These results demonstrate that reduced tillage can be used without negatively affecting rice production. As an additional benefit, reduced tillage has been shown to decrease the environmental impact of rice production. Imazethapyr did not control Indian jointvetch above 70%. Alternative herbicides should be used with imazethapyr if Indian jointvetch is present in fields. This is similar to results of Masson and Webster (2001). Control of Indian jointvetch would be imperative in IT rice for yields in drill-seeded culture to approach those in water-seeded culture.

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CHAPTER 3

IMIDAZOLINONE-TOLERANT RICE RESPONSE TO IMAZETHAPYR APPLICATION

Introduction

In 1993, an imidazolinone-tolerant (IT) rice (*Oryza sativa* L.) line 93-AS-3510 was developed (Croughan 1994). Since then, several rice cultivars tolerant to imidazolinone herbicides have been developed through breeding programs by using 93-AS-3510 as the male parent line. 'CL 121', one IT rice cultivar developed from 93-AS-3510, is currently in commercial production. Another commercially used IT rice cultivar, 'CL 161', was directly developed from a mutated 'Cypress' plant (Wenefrida et al. 2004).

Imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}, an acetolactate synthase (ALS) (E.C.4.1.3.18) inhibitor, is the herbicide labeled for use in IT rice (Anonymous 2000; Masson and Webster 2001). By inhibiting ALS, imazethapyr blocks biosynthesis of branched-chain amino acids valine, leucine, and isoleucine (Stidham 1991) resulting in plant death of susceptible species.

Imazethapyr controls many key weeds such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash], and rice flatsedge (*Cyperus iria* L.) (Anonymous 2000). But more importantly, imazethapyr use in IT rice allows selective control of red rice (*Oryza sativa* L.), a noxious rice biotype, that cannot be controlled by herbicides labeled in conventional rice due to its genetic similarity to cultivated rice (Noldin et al. 1999).

Potential IT rice injury with imazethapyr application is of concern. Steele et al. (1999) reported 16 to 48% rice injury with imazethapyr applied postemergence at 70 to 175 g ai/ha. Sequential applications of imazethapyr at 70 g/ha injured rice 30%. Webster and Masson (2001), however, reported rice injury less than 16% when imazethapyr at 70 g/ha was applied to two-

three-leaf drill-seeded rice or water-seeded rice at pegging when green leaf tissue has emerged from the seed and the root has begun to extend downward into the soil.

CL 121 and CL 161 differ greatly in their tolerance to imazethapyr (Wenefrida et al. 2004). Differential tolerance between CL 121 and CL 161 is due to the IT parent lines used in developing the cultivars. PWC-16, the original IT germplasm for CL 161, is eight times more tolerant than 93-AS-3510, the male parent line for CL 121. However, information is limited on specifically why these differences exist between the two IT cultivars on a physiological level. Herbicides that are ALS inhibitors can reduce transport of photosynthate from source leaves to roots, resulting in root growth inhibition (Devine 1989; Devine et al. 1990; Shaner 1991). The medium-grain cultivar 'Bengal' was less tolerant to bispyribac compared with the long-grain cultivar 'Cocodrie' (Zhang and Webster 2002). They reported that tolerance of rice to bispyribac-sodium {2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate}, an ALS inhibitor, was both cultivar and growth stage dependent. Shoot and root growth of 'Bengal' was inhibited more when bispyribac was applied at one- to two-leaf compared with two- to three-leaf rice. Pantone and Baker (1992) reported that long-grain 'Lemont' rice was less tolerant to triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid than medium-grain 'Mars' rice or long-grain 'Tebonnet' rice. Cultivar tolerance to triclopyr increased as rice growth stage advanced from two- to three-leaf to panicle initiation. In a greenhouse study Webster and Masson (2001) reported that even though imazethapyr negatively affected growth of imidazolinone-tolerant line 93-AS-3510, the rice was able to recover.

Understanding the response of IT rice cultivars to imazethapyr application is important for effective use of this new technology. Therefore, the objective of this study was to evaluate shoot and root growth response of

CL 121 and CL 161 to imazethapyr applied to foliage at various rates and timings.

Materials and Methods

The experiment was conducted in a greenhouse at Louisiana State University in Baton Rouge, Louisiana. The experiment was repeated with the first experiment initiated on January 25, 2002, and second experiment initiated on March 2, 2002. The greenhouse was kept at a day:night temperature of 30:25 \pm 5 and 60 \pm 10% relative humidity. Day length was extended to 14 h with metal halide lamps at a minimum intensity of 270/ μ mol²/s photosynthetic photon flux. The soil used was Commerce silt loam (Fine-silty, mixed, superactive, nonacid, thermic Aeric Fluvaquents) with less than 0.1% organic matter, 80.3% sand, 5.8% silt, 13.9% clay, and pH 7.0.

Plastic cone tubes¹ (3.8 cm in diameter and 21 cm in height) were used to grow plants for effective and accurate sampling of rice roots. A filter paper² was placed at the bottom of each tube to prevent soil loss and allow water movement under the simulated aquatic conditions. One hundred sixty grams of soil was packed into each tube to the level of 0.5 cm from the tube top. CL 121 and CL 161 rice seeds were soaked in water for 24 hours and drained for 12 hours to initiate germination, which is characterized by the emergence of a radical and a coleoptile from the hull. Seeds germinated at a similar time were selected for planting to ensure uniform seedling emergence and growth. One seed was placed on the soil surface of each tube and covered with 25 g soil. The cone tubes were placed in plastic racks and then placed in plastic containers (100 by 57 by 16 cm). Water was added to each container to a depth of 15 cm and maintained on a daily basis throughout the

¹ Cone-tainer, Ray Leach SC-10 Super Cell, Stuewe & Sons, Inc., 2290 Southeast Kilger Island Drive, Corvallis, OR 97333.

² Whatman #1 filter paper, Whatman Inc., 9 Bridewell Place, Clifton, New Jersey, 07014, USA

experiment. At 15 and 30 days after planting, 15 grams of 15-30-15 fertilizer³ were dissolved in 100 ml water and applied into the water of each plastic container.

Imazethapyr at 70 (labeled rate), 140, and 280 g/ha plus a nonionic surfactant⁴ was applied using a CO₂ pressurized backpack sprayer with an application volume of 140 L/ha at 175 kPa at one- to two-leaf rice and three- to four-leaf rice. The experiment was terminated three weeks after the three- to four-leaf herbicide application to reduce potential confounding effects of root growth restriction due to limited soil volume and tube space.

The experiment was a completely randomized design with a three-factor factorial arrangement of treatments with four replications. The experiments were located in same section of the greenhouse unit. Factor A was IT rice cultivars: CL 121 and CL 161. Factor B was imazethapyr rates at 0, 70, 140, and 280 g/ha. Factor C consisted of application timings at one- to two- and three- to four-leaf stage of rice.

Visual estimates of rice injury were determined 1, 2, and 3 weeks after treatment (WAT) on a scale of 0 to 100% with 0 = no injury and 100 = plant death. Injury ratings were based on chlorosis, necrosis, and height reduction. Fresh shoot and root weights were determined 1, 2, and 3 WAT. Each treatment had three sets of plants to accommodate the three sampling dates. At each sampling date the entire contents of the tube were removed and soil was washed from the roots. Following the washing the entire plant was placed between two paper towels and dabbed dry. The shoot and root were separated at approximately one cm below the soil surface line, and fresh weights and heights (or lengths) of each were obtained immediately after

³ Miracle-Gro, Scotts Miracle-Gro Products, Inc., 14111 Scottslawn Road, Marysville, OH 43041, USA.

⁴ Nonionic surfactant Latron AG-98® is a mixture of alkylaryl polyoxyethylene glycols. Rohm and Haas. 100 Independence Mall West, Philadelphia, PA 19106.

separation. Shoot:root ratio was calculated by dividing shoot fresh weight by root fresh weight of each sample. Fresh weight of shoot and root was converted to percent reduction compared with the corresponding nontreated fresh weight of each IT rice cultivar for each evaluation date. Actual fresh weight of nontreated shoot and root were also reported.

All data were subjected to the Mixed Procedure (SAS Institute 1999), with experiments being used as a random-effect parameter. Considering year or experiments as environmental or random effects permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III Statistics were used to test all possible effects of fixed effects or interactions between fixed effects and least square means at $p \leq 0.05$ were used for mean separation.

Results and Discussion

Imidazolinone-tolerant cultivar by imazethapyr rate by application timing interaction occurred for rice injury at 2 WAT (Table 3.1). Injury of CL 121 increased from 37 to 67% as imazethapyr rate increased from 70 to 280 g/ha for the one- to two-leaf application and from 12 to 78% for the three- to four-leaf application. Injury to CL 121 with 70 or 140 g/ha of imazethapyr was reduced when applied at the three- to four-leaf stage. CL 161 was injured no more than 14% with imazethapyr regardless of rate or application timing. At 3 WAT when averaged across application timings, CL 121 was injured 38% with imazethapyr at 280 g/ha, which was greater than that for the lower rates (18 and 23% injury) (Table 3.1). In contrast, injury of CL 161 with imazethapyr at 280 g/ha was 11% and no more than 5% for the lower rates.

For shoot fresh weight (expressed as percent reduction compared with the nontreated), data for both 2 and 3 WAT were averaged over application timings. At 2 WAT, percent reduction in shoot fresh weight of CL 121 was 36 to 66% (Table 3.2). The reduction was greater with imazethapyr at 280 g/ha

Table 3.1. Rice injury for two imidazolinone-tolerant rice cultivars 2 and 3 weeks after treatment (WAT) as influenced by imazethapyr rate and application timing at Baton Rouge, Louisiana in 2002.

		Rice injury ^a		
Rice		2 WAT		
cultivar	Imazethapyr rate	1-2 leaf	3-4 leaf	3 WAT ^b
	g ai/ha	%		
CL-121	70	37 d	12 fg	23 b
	140	47 c	24 e	18 bc
	280	67 b	78 a	38 a
CL-161	70	6 gh	5 h	1 d
	140	14 f	9 fgh	5 cd
	280	13 f	5 h	11 c

^aMeans followed by same letter within each rating interval are not significantly different at $p \leq 0.05$.

^bData averaged over application timings and two experiments.

Table 3.2. Fresh weight of rice shoots of two imidazolinone-tolerant rice cultivars 2 and 3 weeks after treatment (WAT) as influenced by imazethapyr rate at Baton Rouge, Louisiana in 2002.

Imazethapyr rate	Shoot fresh weight ^{ab}	
	CL 121	CL 161
g ai/ha	reduction, %, 2 WAT	
70	36 b	0 a
140	29 b	0 a
280	66 c	1 a
Nontreated (g) ^c	(1.31)	(1.40)
	reduction, %, 3 WAT	
70	10 b	0 a
140	11 b	0 a
280	41 c	14 b
Nontreated (g)	(4.0)	(5.46)

^aShoot fresh weight is expressed as percent reduction compared with the nontreated and is averaged over application timings of one- to two-leaf and three- to four-leaf rice and two experiments.

^bMeans followed by same letter within each rating interval are not significantly different at $p \leq 0.05$.

^cThe actual shoot fresh weight of the respective nontreated control is presented in parentheses.

compared with 70 and 140 g/ha. For CL 161 fresh shoot weight, 2 WAT was not negatively affected by imazethapyr. At 3 WAT, shoot fresh weight of CL 121 was reduced around 10% with imazethapyr at 70 and 140 g/ha, but was reduced 41% with imazethapyr applied at 280 g/ha. Shoot weight of CL 161 was not affected by imazethapyr at 70 and 140 g/ha, but was reduced 14% when imazethapyr rate was increased to 280 g/ha. Of interest is that from 2 to 3 WAT, shoot fresh weight more than tripled for both cultivars when imazethapyr was not applied.

For root fresh weight (expressed as percent reduction compared with the nontreated), data for both 2 and 3 WAT were averaged over application timing. Root fresh weight for CL 121 was reduced 57% with imazethapyr at 280 g/ha at 2 WAT and 52% for the same rate at 3 WAT (Table 3.3). For imazethapyr at rates of 70 and 140 g/ha, root fresh weight was reduced around 25% 2 WAT and around 10% 3 WAT. For CL 161, percent root fresh weight was reduced no more than 8% when imazethapyr was applied at 280 g/ha, but no negative effect was observed for 70 and 140 g/ha. As also noted for shoot fresh weight, root fresh weight where imazethapyr was not applied more than tripled from 2 to 3 WAT. Based on percent growth reduction, CL 121 response to imazethapyr appeared fairly consistent when considering shoot and root growth compared with a nontreated control. This clearly indicates that herbicide translocation occurred throughout the plant and that suppression of growth on a whole plant basis was affected. The results also demonstrate the ability of CL 121 to rapidly recover from the negative effect of imazethapyr over time, especially for the 70 and 140 g/ha rates.

Averaged over imazethapyr timings, shoot:root ratio for CL 161 was 1.05 to 1.08 with no difference observed between the nontreated and any imazethapyr treatment (Table 3.4). For CL 121, however, shoot:root ratio was lower than that observed in CL 161 where imazethapyr was applied. This

Table 3.3. Fresh weight of rice roots of two imidazolinone-tolerant rice cultivars 2 and 3 weeks after treatment (WAT) as influenced by imazethapyr rate at Baton Rouge, Louisiana in 2002.

Imazethapyr rate	Root fresh weight ^{ab}	
	CL 121	CL 161
g ai/ha	reduction, %, 2 WAT	
70	29 c	0 a
140	21 c	0 a
280	57 d	4 b
Nontreated (g) ^c	(1.32)	(1.30)
	reduction, %, 3 WAT	
70	11 b	0 a
140	10 b	0 a
280	52 c	8 b
Nontreated (g)	(4.40)	(4.83)

^aRoot fresh weight is expressed as percent reduction compared with the nontreated and is averaged over application timings of one- to two-leaf and three- to four-leaf rice and two experiments.

^bMeans followed by same letter within each rating interval are not significantly different at $p \leq 0.05$.

^cThe actual root fresh weight of the respective nontreated control is presented in parentheses.

Table 3.4. Rice shoot:root ratio of two imidazolinone-tolerant rice cultivars 2 weeks after treatment (WAT) as influenced by imazethapyr rate at Baton Rouge, Louisiana in 2002.

Imazethapyr rate	Shoot:root ratio ^{ab}	
	CL 121	CL 161
g ai/ha		
70	0.88 b	1.08 a
140	0.88 b	1.07 a
280	0.73 c	1.08 a
Nontreated	0.98 ab	1.05 a

^aShoot:root ratio is calculated by dividing shoot fresh weight by root fresh weight and averaged over application timings of one- to two-leaf and three- to four-leaf rice and two experiments.

^bMeans followed by same letter are not significantly different at $p \leq 0.05$.

indicates that for CL 121, shoot fresh weight was inhibited more by the application of imazethapyr than was root fresh weight. Of interest is that shoot:root ratio 3 WAT was not affected by imazethapyr application (data not shown) indicating that the ratio would not be a strong indicator for imazethapyr tolerance in rice. Zhang and Webster (2002) showed that for bispyribac, another ALS inhibitor, shoot:root ratio was a strong indicator for rice tolerance.

These results indicate that CL 161 is inherently more tolerant to imazethapyr than is CL 121 based on visual injury and shoot and root growth. Using the recommended rate of 70 g/ha imazethapyr and the shoot fresh weight data 2 WAT, CL 161 is 1.8 times more tolerant than CL 121 and 1.3 times more tolerant at 3 WAT. Using root fresh weight data 2 WAT, CL 161 is 1.6 times more tolerant than CL 121 and 1.4 times more tolerant at 3 WAT. Differential tolerance between CL 121 and CL 161 is due to IT parent lines used in developing the cultivars (Wenefrida et al. 2004). PWC-16, the original IT germplasm for CL 161, is 8 times more tolerant than 93-AS-3510, the male parent line for CL 121. Our research suggests that even though the two cultivars differ in their tolerance to imazethapyr, the magnitude of the difference is not nearly as high as that reported for the parent lines (Wenefrida et al. 2004). In their research, seed germination was used to evaluate level of susceptibility of the parent line to imazethapyr. The magnitude of the difference in response between our research and that of Wenefrida et al. (2004) could be related to several factors to include imazethapyr rate, time period following application, or the plant growth parameter used to make the comparison between cultivars. Regardless, growers should expect CL 121 to be more sensitive to imazethapyr and for recovery to occur over time. This study did not measure grain yield, but other research has shown that yield of CL 121 was not negatively affected by imazethapyr applied at labeled rates (Pellerin et al. 2003).

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CHAPTER 4
INFLUENCE OF RICE PRODUCTION SYSTEMS ON OFF-SITE MOVEMENT OF SOLIDS
Introduction

Water seeding is the predominant planting method used in Louisiana rice (*Oryza sativa* L.) production, especially in the southwest rice-growing area. The primary reason for the popularity of water seeding is that it creates a soil environment that allows rice germination but prevents red rice (*Oryza sativa* L.), a noxious rice biotype, from germinating (Dunand 1988). In addition, water seeding can be easily adapted to crawfish production, which is an important commodity in the region (Linscombe et al. 1999). In a typical water-seeded system, a rice field is mechanically tilled under flooded conditions to destroy established red rice and other weeds, and to establish a smooth, level and uniform seedbed - a cultural practice referred to as "mudding in". Presprouted rice seeds are broadcasted into the flooded field. The field is then drained for three to five days, which is long enough for the presprouted rice seeds to anchor into the soil, but not sufficient time for red rice seeds in the soil to germinate. The rice field is reflooded and the flood is maintained until rice nears maturity. Water-seeding in combination with precise (pinpoint flood) water management has been very effective in suppressing red rice competition, which can reduce both rice yield and grain quality (Dunand 1988).

Environmental concerns by federal and state entities over water seeding practices, in particular water discharges from rice fields, have been linked to water quality degradation in surface waters (Bollich and Feagley 1995; Cormier et al. 1990; Salassi et al. 2002). Alternative management practices such as no-till, stale seedbed, and reduced tillage can reduce the amount of sediment in water runoff from rice fields (Bollich and Feagley 1995; Feagley et al. 1992); however, poor rice seedling establishment and inconsistent red

rice control are associated with reduced tillage practices (Bollich and Feagley 1995; Linscombe et al. 1999).

Imidazolinone-tolerant rice has been commercialized since 2000 (Anonymous 2000). Rice resistant to glufosinate [ammonium-DL-homoalanin-4-yl(methyl)phosphinate], although not commercialized has also been evaluated (Braverman and Linscombe 1993; Sankula et al. 1997a). Using imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} in imidazolinone-tolerant rice or glufosinate in glufosinate-resistant rice allows selective control of red rice and other weeds with minimal injury to rice (Sankula et al. 1997b; Masson and Webster 2001; Pellerin et al. 2003). Use of these new technologies may offer the possibility to control red rice with production systems other than water-seeding (Bollich et al. 2002). Adoption of more environmentally friendly practices such as no-till, stale seedbed, and reduced tillage in conjunction with new weed management technologies could potentially reduce the amount of sediment runoff from discharges of irrigation water in rice without sacrificing weed control.

Information is limited on how rice production systems involving tillage, seeding method, water management, rice cultivar, and herbicide might affect sediment runoff from fields. Such information would be important in developing best management practices (BMPs) in terms of protecting the environment and improving agricultural productivity. Therefore, the objective of this study was to evaluate various rice production systems in regard to off-site movement of solids as affected by release timing of rice drainage water.

Materials and Methods

A field study was established in 2000 and 2001 at the Rice Research Station near Crowley, LA, on a Crowley silt loam soil (Typic Albaqualf, fine montmorillinitic, thermic) with a pH of 5.5 and 1.4% organic matter. The

experimental design was a randomized complete block with two replications. The study consisted of seven treatments (production systems) with tillage, seeding method, and water management as components. The specific components in the rice production systems are presented in Table 4.1.

Plot size was 3.7 by 18.3 m in 2000 and 3.7 by 12.2 m in 2001. Each plot was separated with a levee system to maintain plot identity. Water entered on one end of each plot and exited on the opposite end to prevent cross contamination. Tillage treatments consisted of conventional and reduced tillage. For conventional plots seedbed preparation included a fall disking followed by spring disking and two passes in the opposite direction using a two-way bed conditioner equipped with rolling baskets and s-tine harrow set to operate at a six cm depth. Reduced tillage plots received no mechanical seedbed preparation in the spring. Two weeks prior to seeding, the reduced tillage area was sprayed with glyphosate [N-(phosphonomethyl) glycine] at 0.84 kg ae/ha to control existing vegetation.

Seeding methods included drill-seeding and water-seeding. The drill-seeded plots were planted on May 25, 2000, and June 8, 2001, at a seeding depth of 1.5 cm, with a 19 cm row width, and at a seeding rate of 112 kg/ha. After drill-seeding the entire experimental area was surface irrigated to 10.2 cm. Water was held for 48 hours and released (initial drain). In water-seeded plots to simulate soil preparation in the flood (Systems 2 and 3), a 2.4 m wide wooden blade (9 by 14 cm) was pulled across plots and sediment in water was allowed to settle for 24 hours. Water-seeded plots were planted on May 26, 2000, and June 9, 2001. Pregerminated rice seeds were hand broadcasted at a rate of 168 kg/ha into the standing water. The plots were drained 24 hours later (initial drain). The date for the initial drain for each year was the same for drill-and water-seeded plots. Permanent flood was established on pinpoint flood plots (Systems 1 and 2) June 3, 2000 and

Table 4.1. Treatment components included in the various rice production systems at Crowley, Louisiana in 2000 and 2001.

Rice production system ^a	Tillage		Seeding method ^b		Water management ^c		
	Conventional	Reduced	Drill	Water	Soil preparation in flood	Pinpoint flood	Delayed flood
1	√			√		√ (6/3;6/17)	
2	√			√	√ (5/25;6/8)	√ (6/3;6/17)	
3	√			√	√ (5/25;6/8)		√ (6/24;7/8)
4	√			√			√ (6/24;7/8)
5		√		√			√ (6/24;7/8)
6	√		√				√ (6/24;7/8)
7		√	√				√ (6/24;7/8)

^aFor each production system the components included are indicated by checks (√).

^bRice was drill-seeded on 5/25/00 and 6/8/01 and water-seeded on 5/26/00 and 6/9/01.

^cSpecific dates are provided in parentheses and represent the first and second year of the study.

June 17, 2001, seven days after initial drain. Permanent flood was established on delayed flood plots (Systems 3, 4, 5, 6, and 7), June 24, 2000, and July 8, 2001, 28 days after initial drain. All plots that did not have permanent floods established prior to sampling date were surfaced irrigated to 10.2 cm 24 hours prior to drainage. After establishment, permanent flood was maintained at 10.2 cm. All plots were completely drained at two-, four-, eight-, and 12 WAID to simulate loss of flood or draining for insect or disease control. Permanent floods were re-established after drainage until final drain. Final drain was at 12 WAID.

Soil fertility management consisted of 280 kg/ha of 7-21-21 (N-P₂O₅-K₂O) fertilizer preplant and 280 kg/ha of 46-0-0 (N-P₂O₅-K₂O) urea nitrogen applied immediately before the permanent flood establishment. Standard herbicide programs were used and applied with a CO₂-pressurized backpack sprayer calibrated to deliver 140 L/ha at 186 Kpa. Standard agronomic and insect pest management practices were implemented as needed throughout the growing season.

A 1-liter water sample was collected from each plot two minutes after initiating drainage to rid flood pipe of any collected solids at all sampling dates. The discharged water with solids was allowed to flow into the liter bottle from the flood pipe. Samples were stored in a refrigerator at 4 C. Solids analysis was conducted on each sample by filtering water through a pre-weighed filter paper¹ (9.0 cm in diameter) using an air-driven system. Filter papers with solids were dried at 80 C in an oven for six hours and weighed. The amount of solids in a water sample was calculated by subtracting each filter paper weight from the combined weight (filter paper plus sediment). Amount of solids was reported as kilograms per hectare and

¹Whatman #1 filter paper, Whatman Inc., 9 Bridewell Place, Clifton, New Jersey, 07014, USA.

was calculated based on solids in the one-liter water sample and liters of water in one-hectare area with a water depth of 10.2 cm.

Solids data were subjected to the Mixed Procedure (SAS Institute 1999) with year being used as a random-effect parameter. Considering year or combination of year and location as environmental or random effects permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Drainage timing was used as a variable in data analysis, which allows comparisons to be made between and among drainage timings. Type III Statistics were used to test all possible effects of fixed effects (production system, drainage timing, and production system by drainage timing) and least square means at $p \geq 0.05$ were used for mean separation.

Results and Discussion

A rice production system by drainage timing interaction was observed, indicating that loss of solids for the production systems varied in respect to the release timing of rice drainage water. Off-site movement of solids at the initial drain for water-seeded rice under conventional tillage (Systems 1, 2, 3, and 4) ranged from 690 to 1250 kg/ha (Tables 4.2 and 4.3). Under the conventional system where rice was water-seeded with soil preparation performed in the flood (Systems 2 and 3), loss of solids in the initial drain was 920 and 1250 kg/ha. Even though these values were significantly different, this was probably an anomaly because the treatments components were the same when solids were collected at the initial drain. For practical purposes off-site movement of solids for the plots where soil was prepared in the flood was equal to the other conventional treatments. In contrast, loss of solids under reduced tillage (Systems 5 and 7) at initial drain was no more than 80 kg/ha regardless of whether rice was drill- or water-seeded. Reduced tillage practices reduced the loss of solids in the initial drain by

Table 4.2. Off-site movement of solids under various rice production systems at different drainage timings averaged over years at Crowley, Louisiana in 2000 and 2001.

Production systems ^b	Loss of solids ^a					
	Initial drain ^c	2 WAID ^d	4 WAID	8 WAID	12 WAID	Total
	kg/ha					
1	930 ab (67%)	190 f-h (14%)	150 f-h (11%)	60 gh (4%)	50 gh (4%)	1380 b
2	920 b (68%)	220 f-h (16%)	110 f-h (8%)	60 gh (4%)	40 h (3%)	1350 bc
3	1250 a (53%)	620 b-e (26%)	370 d-g (16%)	70 gh (3%)	60 gh (3%)	2370 a
4	690 bc (59%)	170 f-h (15%)	170 f-h (15%)	30 h (3%)	100 f-h (9%)	1160 bc
5	80 gh (16%)	160 f-h (32%)	170 f-h (34%)	60 gh (12%)	30 h (6%)	500 d
6	620 b-e (56%)	210 f-h (19%)	160 f-h (15%)	70 gh (6%)	40 h (4%)	1100 bcd
7	70 gh (10%)	210 f-h (31%)	240 f-h (35%)	80 gh (12%)	80 gh (12%)	680 cd

^aMeans followed by same letter within the table are not significantly different at $p \leq 0.05$. Values in parentheses represent percentage of total loss of solids for individual drainage timings.

^bSee Table 4.1 for specific treatment components of the rice production systems.

^cInitial drain conducted 5/27/00 and 6/10/01.

^dWAID, weeks after the initial drainage.

Table 4.3. Off-site movement of solids under various rice production systems averaged over years at Crowley, Louisiana in 2000 and 2001.

Production systems ^a	2	3	4	5	6	7	Loss of solids ^b
	P-values						kg/ha
1	0.8661	0.0050	0.5241	0.0116	0.4033	0.0391	1380 b
2		0.0033	0.6385	0.0172	0.5030	0.0558	1350 bc
3			0.0010	<0.0001	0.0006	<0.0001	2370 a
4				0.0488	0.8401	0.1393	1160 bc
5					0.0738	0.5933	500 d
6						0.1981	1100 bcd
7							680 cd

^aSee Table 4.1 for specific treatment components of the rice production systems.

^bDifferences between means can be compared using p-values ($p \leq |t|$) in the table or using letters in the total column with means followed by same letter not significantly different at $p \leq 0.05$.

at least 7.8 fold. Based on off-site movement of solids over the five drainage timings loss of solids in the initial drain was 53 to 68% for conventional tillage but no more than 16% for the reduced tillage system. These findings clearly show the benefit of reduced tillage on off-site movement of total solids and results agree with those reported by Bollich and Feagley (1995) and Feagley et al. (1992). Loss of solids 2 WAID was 620 kg/ha for water-seeded rice under conventional tillage where soil preparation was performed in the flood and when delayed flood water management was used (System 3) (Table 4.2). Off-site movement of solids for this system was greater than for the other systems. When expressed as percent of total loss of solids, loss 2 WAID was around 30% for reduced tillage systems where delayed flood water management was used (Systems 5 and 7). Percent of off-site movement of total solids 2 WAID was 14 to 26% for the other systems.

At 4 WAID, loss of solids was 110 to 370 kg/ha and differences among the production systems were not observed (Table 4.2). Percent of off-site movement of total solids 4 WAID, however, was around 35% under the reduced tillage systems which compares with no more than 16% for the conventional tillage systems. Loss of solids 8 WAID was no more than 80 kg/ha and no more than 100 kg/ha for 12 WAID. For both the 8 and 12 WAID timings, differences in loss of solids were not noted among the production systems. Percent of off-site movement of total solids was no more than 12% 8 and 12 WAID.

Total off-site movement of solids from the initial drain to 12 WAID for conventional tillage rice where soil preparation was performed in the flood and delayed flood water management was used was 2370 kg/ha, which was greater than any of the other production systems (Table 4.2). Where reduced tillage was used total off-site movement of solids was 500 kg/ha for water-seeded rice and 680 kg/ha for drill-seeded rice and loss of solids was equal for the two production systems. Based on these loss of solids values, use of reduced tillage programs reduced total off-site movement of solids as much as 79%

compared with conventional tillage rice where soil preparation was performed in the flood and where a delayed flood water management system was used.

Results of this study clearly show that rice production systems using conventional tillage practices can contribute to significant loss of solids in discharge of irrigation water. For the conventional tillage systems evaluated in this study, the majority of off-site movement of solids (53 to 68%) occurred in the initial drain and 74 to 84% of the total loss occurred at the initial drain and 2 WAID. In contrast, for the reduced tillage systems total loss of solids was 38 to 79% less when compared with the conventional systems. For the reduced tillage systems, loss of solids at the initial drain was no more than 16% of the total loss and most of the loss (66%) occurred at 2 and 4 WAID. Bollich and Feagley (1995) reported a 3-fold reduction in total solids in rice field drainage water where no-till practices were used compared with a conventional system where soil preparation was performed in the flooded field.

Best management practices to reduce off-site movement of solids from rice fields should include use of reduced tillage practices for rice in drill-seeded or water-seeded production. This research indicates that there was a significant reduction of solids in the discharge of irrigation water for drill-seeded or water-seeded rice in reduced tillage systems compared with conventional tillage with tillage after flood establishment and a delayed flood water management program. Previous information considered all water-seeded rice production systems to be the sources of solids in discharge of irrigation water regardless of tillage practices. These losses are considered major non-point sources of solids in waterways in Louisiana and, these water-seeded systems are considered environmentally unsound practices. However, with proper reduced tillage practices solids can be reduced in water-seeded rice production. For conventional tillage systems evaluated in this study, the majority of total off-site movement of solids (53 to 68%)

occurred in the initial drain compared with reduced tillage systems where no more than 16% of the loss was in the initial drain. There were no differences at 4, 8, and 12 WAID among the seven production systems for loss of solids. In the past, water-seeding has been necessary for control of red rice (Dunand 1998). Advances in technology with imidazolinone-tolerant rice (Masson and Webster 2001; Pellerin et al. 2003) and glufosinate-resistant rice (Sankula et al. 1997a; Sankula et al. 1997b) offer the possibility to control red rice in drill-seeded or water-seeded rice. Adoption of reduced tillage programs in drill-seeded or water-seeded rice production systems in conjunction with new weed management technologies should reduce off-site movement of solids from discharge of irrigation water in rice without sacrificing weed control or yield.

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CHAPTER 5

SUMMARY

Development and commercialization of imidazolinone-tolerant (IT) rice make it possible for selective control of red rice, a noxious rice biotype, in rice. This new technology not only provides an effective tool for weed control, but also may change rice cultural practices used to reduce red rice infestation. A field study was conducted over three years to evaluate crop response and weed control with imazethapyr under conventional and reduced tillage programs in both drill- and water-seeded culture using IT rice. Imazethapyr applied preemergence (70 or 105 g ai/ha) and followed by a postemergence application (70 g/ha) controlled barnyardgrass, Amazon sprangletop, rice flatsedge, and red rice 87 to 99% 5 weeks after postemergence application regardless of tillage system or seeding method. Control of Indian jointvetch with imazethapyr was greater in the water-seeding system but was no more than 75% 5 weeks after postemergence treatment. Where imazethapyr was applied, days to 50% heading, seed per panicle, seed weight, and percent seed harvest index were not affected by tillage system or seeding method. Culm number and culm weight were greater in a conventional tillage system compared with reduced tillage when imazethapyr was applied, but these parameters were not affected by seeding method. Rice grain yield when imazethapyr was applied preemergence followed by postemergence was greater in water-seeded compared with drill-seeded rice.

Imazethapyr applied sequentially to IT rice provided excellent control of many key weeds including red rice in both water- and drill-seeded systems, even when tillage operations were eliminated. Alternative herbicides should be used in conjunction with imazethapyr if Indian jointvetch is present in fields. Control of Indian jointvetch would be imperative in IT rice for yields in drill-seeded culture to approach those in water-seeded culture.

This research compares weed control in water-seeded and drill-seeded methods in both conventional and reduced tillage systems. The results clearly show that imazethapyr applied sequentially to IT rice can provide control of many key weeds including red rice and Amazon sprangletop in both water-seeded and drill-seeded systems, even when tillage operations are eliminated. No differences in tillage systems for weed control, days to 50% heading, seed number or weight per panicle, percent seed, panicle height, lodging, or yield were observed. These results demonstrate that reduced tillage can be used without negatively affecting rice production.

A greenhouse study was conducted to evaluate shoot and root growth response of IT rice cultivars, CL 121 and CL 161 to imazethapyr applied to foliage at one- to two-leaf and three- to four-leaf at 70 to 280 g/ha. CL 161 is inherently more tolerant to imazethapyr than is CL 121 based on visual injury and shoot and root growth. Using the recommended rate of 70 g/ha imazethapyr and the shoot fresh weight data 2 weeks after treatment, CL 161 is 1.8 times more tolerant than CL 121 and 1.3 times more tolerant at 3 weeks after treatment. Using root fresh weight data 2 weeks after treatment CL 161 is 1.6 times more tolerant than CL 121 and 1.4 times more tolerant at 3 weeks after treatment. Differential tolerance between CL 121 and CL 161 is due to IT parent lines used in developing the cultivars. PWC-16, the original IT germplasm for CL 161, is 8 times more tolerant than 93-AS-3510, the male parent line for CL 121. Our research suggests that even though the two cultivars differ in their tolerance to imazethapyr, the magnitude of the difference is not nearly as high as that reported for the parent lines. The magnitude of the difference in response could be related to several factors to include imazethapyr rate, time period following application, or the plant growth parameter used to make the comparison between cultivars. Regardless, growers should expect CL 121 to be more sensitive to imazethapyr and for recovery to occur over time.

A field study was conducted two years at the Rice Research Station near Crowley, LA, to evaluate effects of conventional and reduced tillage rice production systems on off-site movement of solids from the release of drainage water at from fields. Total off-site movement of solids from the initial drain to 12 weeks after initial drainage for conventional tillage rice where soil preparation was performed in the flood where delayed flood water management was used was 2370 kg/ha, which was greater than for the less intensive production systems. Where reduced tillage was used total off-site movement of solids was 500 kg/ha for water-seeded rice and 680 kg/ha for drill-seeded rice and loss of solids was equal for the two production systems. Based on loss of solids values, use of reduced tillage programs reduced total off-site movement of solids as much as 79% when compared with conventional tillage rice where soil preparation was performed in the flood and where delayed flood management was used.

Results show that rice production systems where conventional tillage practices are used contribute to significant loss of solids in discharge of irrigation water. For the conventional tillage systems evaluated in this study the majority of off-site movement of solids (53 to 68%) occurred in the initial drain and 74 to 84% of the total loss of solids occurred at the initial drain and 2 weeks later. In contrast, for the reduced tillage systems total off-site movement of solids was 38 to 79% less when compared with the conventional systems. For the reduced tillage systems, loss of solids at the initial drain was no more than 16% of the total off-site movement of solids and 66% of the total loss occurred at 2 and 4 weeks after the initial drain. These losses are considered major non-point sources of solids in waterways in Louisiana and, these water-seeded systems are considered environmentally unsound practices. However, with proper reduced tillage practices solids can be reduced in water-seeded rice production.

Availability of IT rice offers the possibility to control red rice in a drill-seeded system as effectively as in a water-seeded system. A shift toward use of drill-seeded IT rice and the adoption of reduced tillage programs can reduce off-site movement of solids from discharge of irrigation water in rice without sacrificing weed control.

**APPENDIX: HERBICIDE CONCENTRATIONS IN DRAINAGE WATER UNDER VARIOUS RICE
PRODUCTION SYSTEMS AVERAGED OVER YEARS**

Production systems ^a	Herbicide loss				
	Initial drain	2 WAID ^b	4 WAID	8 WAID	12 WAID
	µg/L ^c				
1 ^d	36	4	2	ND	ND
2 ^d	473	30	2	ND	ND
3 ^e	18	3	ND	ND	ND
3 ^f	ND ^g	ND	ND	ND	ND

^a1 = conventional tillage, water-seeded, pinpoint flood, 2 = conventional tillage, water-seeded, soil preparation performed in the flood, pinpoint flood, and 3 = reduced tillage, drill-seeded, delayed flood.

^bWAID, weeks after initial drainage.

^cµg/L, micrograms per liter.

^dRepresents molinate loss. Molinate applied at 4490 g ai/ha preplant.

^eRepresents clomazone loss. Clomazone applied at 449 g ai/ha preplant.

^fRepresents propanil loss. Propanil applied at 4490 g ai/ha to three- to four-leaf rice.

^gND, none detected.

VITA

Ronald Joseph Levy, Jr., is the son of Ronald and Genevieve Levy. Born on February 15, 1956, he grew up in the town of Bogalusa in Washington Parish, Louisiana. He attended Bogalusa High School and graduated with honors in 1974. Ronald attended Southeastern Louisiana University and received the degree of Bachelor of Science in animal science in May 1979.

In July 1979, Ronald went to work for the Louisiana Cooperative Extension Service in Calcasieu Parish as Assistant County Agent. While working, he continued his education at Louisiana State University and received the degree of Master of Science in December 1986. He then moved to Acadia Parish to work with rice and was promoted to County Agent. In spring 1999, he entered the Louisiana State University Department of Agronomy under the direction of Dr. James Griffin and Dr. Steve Linscombe. Dr. Eric W. Webster has also assisted with his field and greenhouse studies. His dissertation evaluated imidazolinone-tolerant rice response and weed control with imazethapyr using conventional and reduced tillage systems and drill- and water-seeded planting methods.

As a graduate student, Ronald had the opportunity to represent Louisiana State University as a member of the Weed Team for three years. He placed 8th high individual at the Southern Weed Contest in August, 2003. At the Seventh Annual National Conservation Tillage Cotton and Rice Conference, he was selected as the 2004 Rice Researcher of the Year. He is in the process of submitting his dissertation research for refereed journal publication. Ronald is currently a candidate for the degree of Doctor of Philosophy in agronomy.